Mississippi River Updated Stage-Frequency Profiles

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Abstract

Revised stage-frequency profiles for the Mississippi River were developed in the St. Louis District (SLD) from the Lock & Dam 22 tailwater to the Ohio River using updated flow-frequency values. Period of record inflow hydrographs were routed with a current condition unsteady flow model to determine a stage-discharge relationship at each cross section using annual maximum values. A statistical analysis combines the flow-frequency with stage-discharge to determine stage-frequency values at each individual cross section. The crossover area from the Missouri River to the Mississippi River was of special consideration. In backwater areas upstream of the Missouri River, the methodology required using a coincident stage-probability relationship at each cross section. The frequency profiles were then compared to high water marks obtained after the 1993 and 1995 flood events. The upstream and downstream frequency profiles were coordinated with three Corps of Engineers districts to insure matching profiles.

Introduction

The current estimate of the stage-frequency relationships along the Mississippi River in the SLD was developed following the previous flood of record (1973). The 1973 flood set records for stage along most of the Mississippi River in SLD. The profiles were published in 1979 and used the Mississippi Basin River Model to develop the frequency profiles. Since that study, the Mississippi River has experienced moderate to severe flooding in 1979, 1982, 1983, 1985, 1993, 1994 and 1995. The Great Flood of 1993 broke all the stage and discharge records for the entire SLD reach of the Mississippi River from Thebes, IL (mile 43.7) upstream. Concerns were raised to the accuracy of the current stage-frequency profiles. A Feasibility Study was initiated to update the Mississippi, the Missouri and the Illinois Rivers stage-frequency profiles in the St. Paul, Rock Island, St. Louis, Omaha, and Kansas City districts. Technical studies in SLD began in force in March 1998 and completed in May 2003. This paper will address the development of stage-frequency profiles for the Mississippi River in the SLD area.

ST. LOUIS DISTRICT WATERSHED COVERAGE

The St. Louis District is at the southern end of the upper Mississippi River basin and covers 27,000 square miles. SLD includes 300 miles of the Mississippi River from the tailwater at L & D 22 at Saverton, MO to the mouth of the Ohio River, and the lower 80 miles of the Illinois River from the tailwater at LaGrange L & D to the mouth of the Illinois River.

HYDRAULIC MODELING

Hydraulic modeling was performed using UNET, a one-dimensional unsteady flow hydraulic model able to capture the dynamics of flood wave movement in the Mississippi River (ref. 1). The SLD UNET model was developed for the reach of the Mississippi River from near Hannibal, MO to Cairo, IL, the Missouri River from Hermann, MO to the mouth, and the Illinois River from near Meredosia, IL to the mouth. The Kaskaskia, Big Muddy, Meramec, Cuivre and Salt Rivers hydrographs were inserted at their respective junctions with the Mississippi River. All local tributary inflows entering the Mississippi, Illinois and Missouri Rivers were estimated through individual development of HEC-HMS (ref 3) models.

LEVEE DATA

All existing levee units, both Federal and non-Federal or private, were incorporated into the UNET data set. A number of variables were required for the UNET levee simulation. The top-of-levee elevation data for the storage area/levee unit was linked to the main channel. Two levee connections to the main channel were determined for each levee, one upstream and one downstream along the levee cell. The top-of-levee elevation connection data between adjacent storage areas was developed for overtopping flow between adjacent storage areas if necessary. Failure of all levees in this analysis was elevation dependent using existing or future design elevations at the two levee connections to the main river. Levees were considered effective until they overtopped. Flood fighting efforts by increasing the levee height was not considered for this analysis.

MAINSTEM DISCHARGE/ STAGE DATA

There are five discharge gages on the Mississippi River in the SLD, although one (Louisiana) is stage only with occasional discharge measurements made. The discharge gages are located at the Louisiana, MO gage at River Mile (RM) 282.9, the Grafton, IL gage at RM 218.6, the St. Louis, MO gage at RM 179.60, the Chester, IL at RM 109.9 and the Thebes, IL gage at RM 43.7. These sites were used to calibrate the model to recorded discharge data. In addition to the discharge gages, Mississippi River stage data is also available at 33 sites throughout the 300-mile reach of the Mississippi in the SLD that were used for stage calibration.

UNET MODEL CALIBRATION

The input data for UNET included cross sectional data at approximately one half-mile intervals taken from DTM data, Manning's roughness coefficients, levee definitions and bridge definitions. The model was calibrated to reproduce the flows and stages from a high flow year (1993) and a low flow year (1988). The UNET model calibration is based upon stage calibration at more than 40 stage gages and discharge calibration at 5 discharge gages along the Mississippi, Illinois and Missouri Rivers. This total includes most discharge and staff gages operated by the USGS and Corps on the three rivers within or near the SLD boundaries. The error in flow results at Grafton, IL range from 3% for the high flow year (1993) to 10% for the low flow year (1988) and at St. Louis, MO range from 0.5% for the high flow year (1993) to 3% for the low flow year (1988). Flows and stages at Chester and Thebes, IL gages were of similar accuracy.

HYDROLOGIC FLOW FREQUENCY ANALYSIS GENERAL

A period of record simulation was selected to obtain annual peak flows for flood frequency analysis. The period of 1898 to 1997 was used as the longest period where flows could be reliably estimated for flood frequency analysis. One hundred years of simulated daily data entering SLD from the upper Mississippi River, the Missouri River and the Illinois River as well as daily data from the major tributaries and local inflow areas within SLD was routed with the UNET model for two scenarios. One scenario would be an “unregulated” condition, which removed the impacts of reservoir regulation. The second scenario would be the current condition of “regulated” with reservoir regulation.

A unregulated versus regulated relationship was developed by comparing the unregulated and regulated maximum annual daily flows obtained from the period of record simulation. The estimated log-Pearson III distribution describing unregulated annual maximum daily flows was converted to a regulated curve using this relationship.

UNREGULATED FLOWS FOR PERIOD OF RECORD

The full 100-year period of record, 1898 through 1997 was run for the no-reservoir scenario using the UNET model. Annual peak daily discharge data was determined at the five major discharge gages on the Mississippi River. The period of record flows for the unregulated flows for the gages at Hannibal and Hermann were received from the Rock Island District and the Kansas City District, respectively. Because of the large drainage area size of the Mississippi basin at each gage, instantaneous peak values are typically only 1-2% greater than mean daily. Therefore, mean daily flows were used throughout the analysis.

UNREGULATED FLOW FREQUENCY CURVES

Using the unregulated annual peaks and assuming a log-Pearson III distribution, the unregulated flood frequency distribution was computed using the HEC-FFA, Flood Frequency Analysis, computer program (ref 2) from the at-site gage mean and standard deviation combined with the regional skew coefficient. Based on a separate investigation in the study, a –0.1 regional skew was shown to be the regional skew for the Mississippi River in SLD. The calculated statistics for five Mississippi gages are shown in Table1.

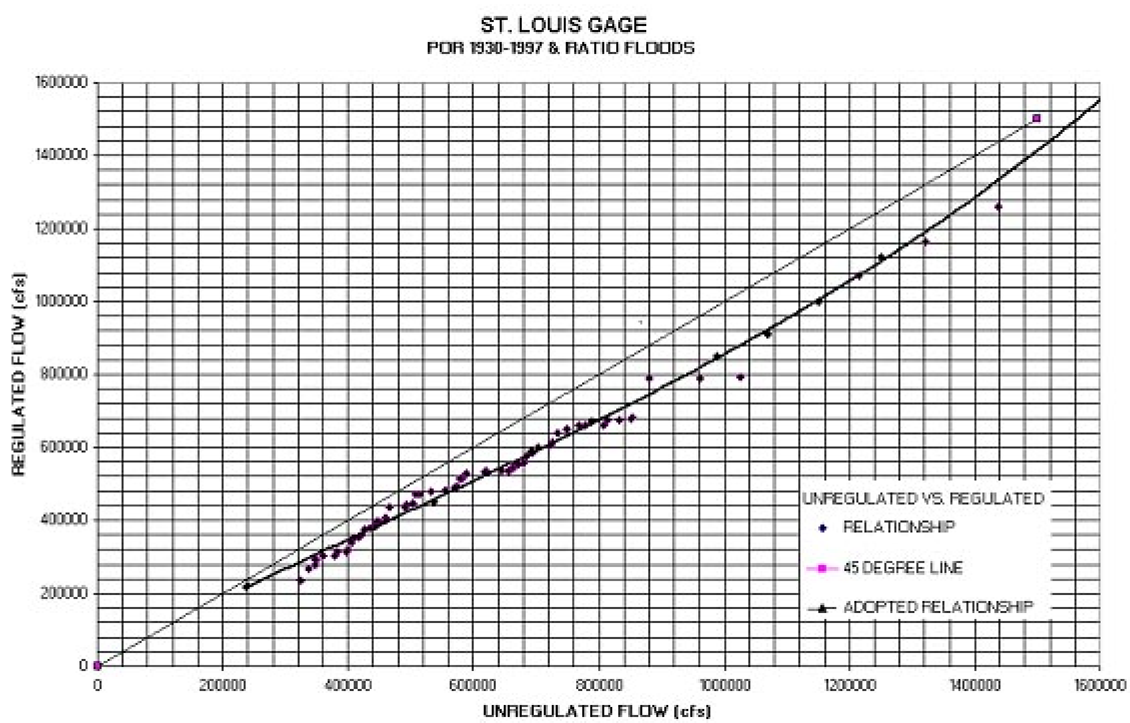
TABLE 1 UNREGULATED ANNUAL FREQUENCY STATISTICS FOR GAGES

	LOUISIANA	GRAFTON	ST. LOUIS	CHESTER	THEBES
MEAN	5.3345	5.4178	5.7272	5.7417	5.7432
STANDARD DEVIATION	0.1495	0.1316	0.1344	0.1352	0.1344
REGIONAL SKEW	-0.1	-0.1	-0.1	-0.1	-0.1

Notes: Means are from peak daily values.
Mean and Standard Deviation are at-site values.

REGULATED-UNREGULATED DISCHARGE RELATIONSHIP

The period of record used for the regulated simulation started in 1930 instead of 1898 as did the unregulated simulation. Kansas City District (KCD) did not have confidence in producing a regulated flow data set prior to1930 at this phase of the study. The annual maximum daily flows from the unregulated and regulated period of record simulations for each gage site were ranked from largest to smallest. Only the unregulated period of record from 1930 to 1997 could be used, since the regulated data set started at 1930. Then, these equally ranked values were plotted against each other to produce a scatter diagram. Rare events are the most critical in defining the upper end of the unregulated-regulated relationship. A best-fit line was then drawn through these points and the relationship was then used to convert the unregulated flow-frequency to regulated flow frequency. The final regulated versus unregulated relationship at the St. Louis, MO gage is shown below.



The final regulated flows and their associated unregulated flows for the same return period are listed for each gage on Table 2.

TABLE 2 FINAL UNREGULATED VS. FINAL REGULATED FLOW-FREQUENCY AT STREAM GAGES

PERCENT	GRAFTON GAGE		ST. LOUIS GAGE	
CHANCE	UNREGULATED	REGULATED	UNREGULATED	REGULATED
EXCEEDANCE	FLOW (CFS)	FLOW (CFS)	FLOW (CFS)	FLOW (CFS)
10	385,000	360,000	791,000	670,000
2	480,000	446,000	991,000	850,000
1	518,000	488,000	1,070,000	910,000
0.2	603,000	585,000	1,250,000	1,120,000

TABLE 2 (CONTINUED) FINAL UNREGULATED VS. FINAL REGULATED FLOW-FREQUENCY AT STREAM GAGES

PERCENT	CHESTER GAGE		THEBES GAGE	
CHANCE	UNREGULATED	REGULATED	UNREGULATED	REGULATED
EXCEEDANCE	FLOW (CFS)	FLOW (CFS)	FLOW (CFS)	FLOW (CFS)
10	819,000	707,000	820,000	709,000
2	1,030,000	893,000	1,030,000	895,000
1	1,110,000	948,000	1,110,000	950,000
0.2	1,300,000	1,140,000	1,300,000	1,142,000

COMPUTING RATING CURVES

Rating curves were developed using the period of record analysis from the year 1898 through the year 2000 using UNET. Kansas City District was able to extend the period of record back to 1898 during the period after the hydrology phase. Tabulations of the annual maximum flow with its associated stage and annual maximum stage with its associated flow for each cross section were performed. The rating curves generated from the unregulated period of record extended the curve beyond the 500-year discharge. A curve was then generated through the data cluster.

Rating curves are affected by levee overtopping and backwater influences. For a levee district, the elevation of levee overtopping, the size of interior drainage area, and the location of breaching can affect the stage and flow patterns of the river system. Annual maximum stage does not always coincide with annual maximum flow when streams are influenced by backwater. The influence of the backwater on an adjoining stream can result in a scatter of data points or a shotgun pattern rating curve when plotting annual maximum stage with the associated discharge values. A trend line cannot be fit in a backwater influenced area. Each rating curve must be investigated to insure a meaningful relationship.

COINCIDENT-STAGE FREQUENCY CURVES

A coincident-stage-probability relationship for each cross section was created using a graphical Weibull approach. Because the data set consisted of a simulated 100-years of record, the graphical approach was used as a guide to the development of the adopted stage frequency. The graphical coincident-stage- probability curves were combined to blend a consistent and reasonable profile for each probability flood for all reaches of the Mississippi River in St. Louis District.

SPECIAL CONSIDERATIONS AT JUNCTIONS

The exchange of stage and flow properties of a larger river system can influence the stage and flow properties on an adjacent river system. The following discussion will examine the junctions on the Mississippi River at the Illinois, the Missouri and the Ohio Rivers and impact of influence that can result during frequency profile development.

The Illinois River is influenced by the stages of the Mississippi River up to La Grange L&D (RM 80.2). When backwater extends a significant distance upstream of the junction, a total probability theorem can be applied to determine frequencies. This probability theorem would account for all events in the family of stages and discharges to determine the probability. The coincident probability method was used for the current Illinois River profiles using duration at the Grafton gage and frequency discharge at the Meredosia gage. The current Illinois River profiles were developed in early 1980. At that time a comparison of stage frequency and coincident frequency analysis was made at gages having a period of record from 1939-1979. The comparison showed that a reliable reproduction of the coincident frequency was similar up to the 10-year event. The two curves followed the general trend but deviated above the 50-year event. In this current analysis, increasing the period of record to 100-years will improve the graphical frequency curve approach. The coincident annual events tabulated using the Weibull method will result in an analysis capturing (in part) the total probability analysis during the 100 year of record.

The peninsula of land in the St. Charles County at the confluence of the Mississippi and the Missouri Rivers is commonly known as the “crossover area”. Flows on the Missouri River exceeding the 20-year discharge, overflow the levee and cross the St. Charles peninsula. The floodwater enters the Mississippi below the Grafton gage or goes into storage in the crossover area. The result is that flows are reduced below the levee breach on the Missouri River and flows are increased below the Grafton gage on the Mississippi. This exchange of flows on the Mississippi River has caused backwater effects upstream on the Mississippi and Illinois Rivers. A continuous flow reduction on the Missouri River will occur from the levee breach to the mouth.

The junction of the Middle Mississippi River and the Ohio River is River Mile 953.8 on the Lower Mississippi River or River Mile 981.5 on the Ohio River. The adopted stage-frequency at this location by the Memphis District is shown on Table 3. The stage probability at the junction is fixed, since analysis beyond the junction of the Mississippi and Ohio Rivers was beyond the scope of this study. The Ohio River stages can affect stages on the Mississippi River up to the Cape Girardeau Gage (RM 52.0). Because of the need to match the current profiles at the junction of the Ohio River/Lower Mississippi River, a horizontal line for each profile event at the junction was extended upstream until it intersected its respective coincident stage-frequency elevation.

TABLE 3 STAGE-FREQUENCYAT MISSISSIPPI & OHIO RIVER JUCTION

Frequency	Elevation
Ohio/Mississippi River	Ft (NGVD)
10 %	323.0
2 %	329.0
1 %	330.3

PROFILE COORDINATION AT DISTRICT BOUNDARIES

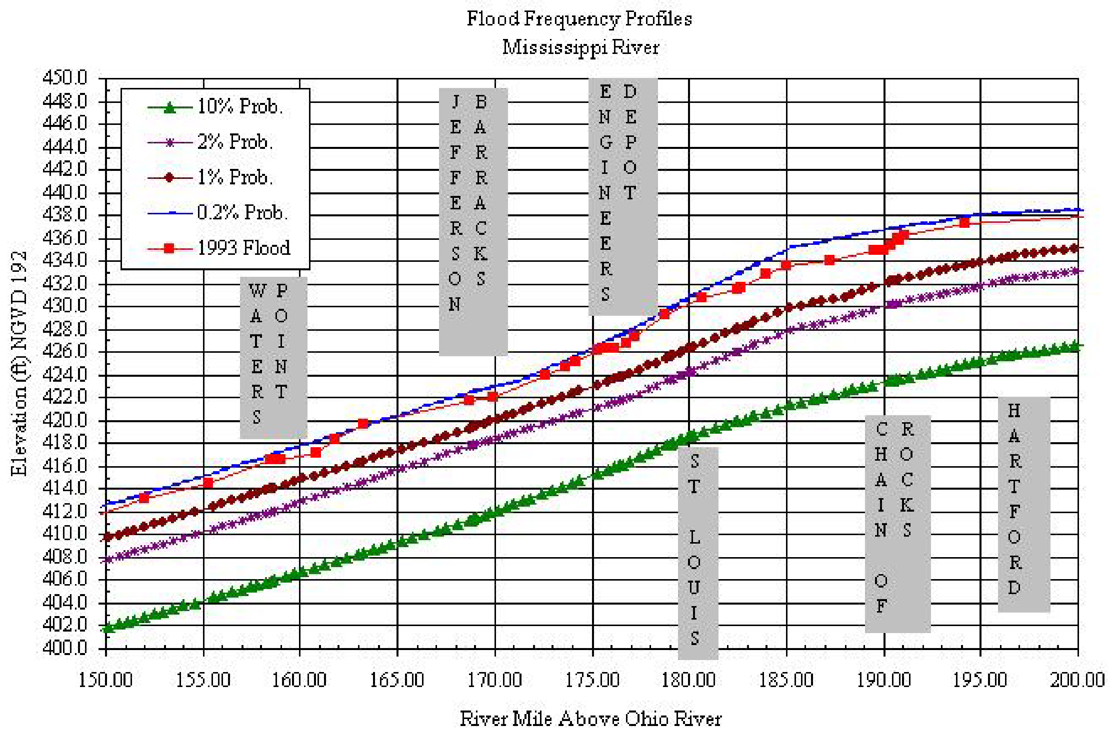
At the junction of the Ohio River and the Mississippi River, the new St. Louis District profiles were blended into the existing water surface profiles currently published. Close coordination with Kansas City District (NWK) and Rock Island District (MVR), provided for matching profiles at the junction of the Missouri River with the Mississippi River, the Mississippi River at L&D 22, and the Illinois River at LaGrange Lock and Dam.

FLOOD FREQUENCY WATER SURFACE PROFILES

Development of the frequency profiles for the non-backwater affected reaches of stream is straightforward. The stage for a regulated flow for a given frequency is calculated from the generated rating curve for a given cross section.

The development of the frequency profile for cross sections with backwater influences is a little more complex. This method is especially applicable at the junction of tributaries, which includes the Ohio, Missouri and Illinois Rivers and for the reach of the Illinois River in the St. Louis District. In these areas, the coincident-stage-probability curve from the regulated flow period of record simulation is used to determine the frequency elevations for cross sections.

Stage frequency profiles were computed for the 10%, 2%, 1% and .2% frequency flood events and are shown on the following figure. The 1993 flood the exceeded the 1% chance exceedence frequency and was used to shape the adopted profile.



SUMMARY

This study reflected the best frequency estimates for the Mississippi and Illinois Rivers to date. The 1993 flood showed that the existing profiles at that time could be in error. The stage frequency profiles presented from this study reflected current knowledge of the river system. Reduction or increases of final stage frequency profiles are reflective of the basin current conditions and current hydrologic and hydraulic technology.

REFERENCES

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